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April 1971

ARCTIC DATA BUOY AND POSITIONING SYSTEMS

Arctic Ice Dynamics Joint Experiment
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AIDJEX HAS MOVED.

The AIDJEX Coordinating Office has moved to more spacious quarters. Please note the new address:

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ARCTIC DATA BUOY
THE SOVIET DARMS

by

Serge M. Olenicoff

The RAND Corporation

Santa Monica, California

INTRODUCTION

Of the approximately 13.5 million km$^2$ encompassed by the Arctic Basin, 5 million km$^2$ have remained practically inaccessible to the present day. And, although the amount of observational data accumulated in the Arctic Basin has grown manyfold during the last two decades, it is still relatively sparse and erratic.

Of all the nations engaged in Arctic research, the Soviet Union has been the most active, and understandably so. Whereas research planning among Western scientists tends to be based on the rationale that "it would be useful" to have more accurate and more complete data from the Arctic realm, the motivation for Soviet scientists has always been that such data "must be obtained" to serve an immediate and vital need. Accurate and timely observational data from the Arctic Basin are essential for the preparation of weather forecasts affecting vast areas of the USSR, as well as for ice forecasting and the maintenance of navigation along the Northern Sea Route.

Due to this need, the Soviets have for many years been channeling substantial amounts of effort and resources into their Arctic research program. An extensive network of weather stations operate year-round along the entire arctic coastline of the Soviet Union, and seasonal observations of ice conditions are performed by a large fleet of ice-reconnaissance aircraft, by icebreakers, by ship-based helicopters, and by satellites. In addition, since 1954, the Soviets have had at least two manned drifting stations simultaneously operating in the Arctic Basin at all times (with the exception of 1959-60, when only North Pole-8 was in operation). A considerable amount of data has also been gathered by the annual High
Latitude Air Expeditions that have enabled Soviet scientists to make hundreds of observation-oriented landings all over the Arctic Basin, especially in the otherwise inaccessible central regions. Finally, to supplement the above-mentioned data-gathering methods (all of which are subject to some seasonal, weather, or geographical restrictions), Soviet scientists have developed and deployed Drifting Automatic Radio-Meteorological Stations (DARMS) specially designed to operate and gather data in the pack-ice environment of the Arctic Basin.

THE DARMS

The Soviet DARMS, frequently referred to as the Alekseyev DARMS (for its inventor, Yu. K. Alekseyev*), has been in operation since 1956. It was preceded by two earlier types of automatic drifting stations. These were the Samsoniya radio-buoy (1947) and the Alekseyev radio-beacon (1952). These DARMS predecessors were not equipped to gather any data, and their only function was to automatically transmit signals at specific time intervals. The signals allowed shore stations to take bearings and to thus determine the position of the automatic drifting station. Such positioning was accurate to within ±1.5 degrees and, if continued with regularity, enabled shore observers to map the movements of the radio-beacons and of the large ice fields with which they are drifting. A previous publication by this author [see Bibliography] discusses in detail the construction and operation of these early automatic station models and of the later DARMS.

Figure 1 shows the Soviet DARMS as it appears when installed on the drifting pack ice. A 12-meter Duraluminum radio-mast, which is assembled from sections and also functions as an antenna, rises above the surface of the ice (1). The radio-mast is fastened by a dual set of guy wires (2) to three anchor pegs (3) which are frozen into the ice. The dry batteries and the timing mechanism of the DARMS are enclosed in a hermetically sealed cylinder (4) which is attached to the lower end of a steel shaft and lowered into the

*The Alekseyev-developed DARMS is covered by USSR Invention Patents No. 158637, No. 170851, and No. 171609 (identifying the latest model, which will be discussed in this paper).
Fig. 1 The Soviet DARMS
water through a hole drilled in the ice. This puts the current source and the timing mechanism which activates the station in the most favorable thermal condition, since the water under the ice is at an almost constant temperature (around -1.8°C) and serves as a natural thermostat. The hermetically sealed cylinder is 320 mm in diameter and 1200 mm high. It is hermetically attached to the steel shaft (5) which passes through the ice and is attached to the radio mast. The shaft is hollow and contains the electric cables running from the battery to the radio transmitter (6) and to the meteorological instrument block (7). The steel shaft coming up through the ice is attached to the radio mast through an insulator. Below this separating insulator, at a point 1 meter above the surface of the ice, there are two flanges on the steel shaft. The radio transmitter (6) is connected to one of them and a special angle bracket (9) to the other. The angle bracket holds the meteorological instrument block (7) in a position away from the radio mast and 2 meters above the surface of the ice. The steel shaft (5) which links the below-ice and above-ice sections of the DARMS is, in turn, rigidly held by a special collar (14) supported by three swivel-jointed rods (10). These supporting rods are spaced at 120° and attached to the anchor pegs (3) frozen into the ice. The lower ends of the supporting rods (10) are also connected to the center shaft (5), at the point where it comes out of the ice, by means of spring-wires (11) equipped with turnbuckles (12). Thus, a system of three right triangles is formed (spaced at 120°) with each supporting rod (10) as a hypotenuse.

The three anchor pegs which are frozen into the ice have special guide shoes attached above them. In the event of ice deformation, the guide shoes make it possible for the anchor pegs to shift without toppling the DARMS. If a crack in the ice causes one of the anchor pegs to break off along with a piece of ice floe, the guide shoe will automatically free the end of the supporting rod without harming the mountings. The DARMS will not collapse as a result of this, but will remain standing vertically, supported by its center shaft and the two remaining anchors. Such a system of balanced and flexible supports provides the DARMS with great tenacity under Arctic conditions, enabling it to withstand quite substantial ice tremors and winds of storm proportions. The base of the DARMS is, in addition, shielded from solar radiation so as to minimize temperature errors and ice melting. This
shielding is accomplished by a thermal screen (13) with centered aero-dynamic vents which covers the three anchor pegs and the whole triangular area delineated by them.

The entire DARMS assembly weighs about 230 kg and, when installed, takes up an area of approximately 40 square feet. It is easily transportable by air and can be installed by four men in less than two hours. One plane can carry and install up to five DARMS in the course of one flight. The installation sequence involves (1) landing on the pack ice and unloading the installation crew, their tools, and the DARMS parts, (2) assembling the DARMS radio mast and attaching it to the main DARMS unit, (3) boring holes in the ice for the DARMS centershaf and anchor pegs using a motor drill, (4) setting up the assembled DARMS unit over the prepared site, (5) giving all instruments and connections a final check, (6) activating the automatic station, (7) loading the installation crew and the tools back on the plane, and taking off.

The meteorological instrument block of the DARMS contains all the sensors in one aggregate unit. It is shown in relation to the whole DARMS in Figure 2 and is enlarged in Figure 3. This vaned unit makes all the meteorological measurements, and codes them for transmission. The sensors contained in the instrument block include a thermometer (shielded-thermocouple type), a barometer (aneroid-cell type), an anemometer (not a standard cup unit, but one using two perpendicular vanes), and a compass for determining the direction of the wind relative to magnetic north. The action of the wind on the vanes rotates the instrument block around a vertical axis as it measures the direction and speed of the wind, notes the temperature and pressure of the air, and also collects other information. The sensor readings of the instrument block are then converted into signals and sent out by the DARMS transmitter in the form of a coded dispatch, which is repeated several times and consists of six groups of Morse code letters.

The internal construction of an instrument block is shown in Figure 4. In the center one can see a cylindrical segment, the surface of which is furrowed by numerous grooves. These horizontal grooves consist of alternating vertical strips of metal and insulation, which are code marks arranged in a specific pattern. Each sensor is represented by a pointer situated opposite one of the grooves. When the timing mechanism turns on the DARMS at a prearranged time, or when an interrogating radio signal is
Fig. 2
The Alekseyev DARMS.

Fig. 3
The DARMS instrument block.

Fig. 4
Interior of the DARMS instrument block.
received by the automatic station, an electric motor is activated and the grooved cylinder begins to rotate, periodically touching the tips of the pointers with its rotating surface. Each pointer, upon entering into the proper groove, moves along through it and produces a chain of alternating contacts and breaks of electrical current, which the DARMS radio transmitter then sends out in the form of coded data dispatches.

The DARMS radio transmitter operates on one fixed frequency, usually at 632 kHz. Some DARMS transmit at a lower frequency in the 570-580 kHz range. Ordinarily, the DARMS makes from 4 to 8 transmissions daily, but it can be activated and interrogated at any time by shore stations, ships, or aircraft. Most of the DARMS transmitters operate on 40 w of power (there are apparently some models that operate on only 10 w), with a wavelength of from 430 to 630 meters and a range of up to 1500 km.

The DARMS signals are picked up by coastal direction-finding radio stations, which record the sensor readings and determine the direction and speed of the DARMS drift. These shore stations can obtain bearings on the DARMS with the error not exceeding ± 1.5 degrees. This represents an accuracy of ± 26 km at 1000 km from the station, or ± 13 km at 500 km, and so on. Bearings must, of course, be obtained simultaneously by at least two coastal direction-finding stations in order to determine the geographical coordinates of the DARMS.

One other interesting feature of the Alekseyev DARMS is its ability to send distress signals. As was mentioned earlier, the construction of the automatic station is such that it will maintain its vertical position even if one of its tripod legs is dislodged from the ice. If the station loses a second leg, it can no longer remain vertical and will slowly start to sag. As soon as its structure begins to deviate from a vertical position, an automatic distress signal is switched on and transmitted to the shore stations, informing them that the DARMS is in trouble and about to "die."
SOVIET DEPLOYMENT OF AUTOMATIC STATIONS IN THE ARCTIC

The first year of large-scale Soviet utilization of automatic drifting stations in the Arctic was 1953. At that time, only the early Alekseyev radio-beacons were in service, and only position data were being received. The average life span of the radio-beacons installed in 1953 was relatively short—some ceased sending signals after a few days, others survived for two or three months.

In the next year (1954), the radio-beacons "lived" somewhat longer, on the average, and one station continued transmitting signals until March of 1955. When operating, the stations performed reliably, and good tracking data were obtained.

In the spring months of 1955 and 1956, an additional 28 radio-beacons were set up in various parts of the Soviet Arctic. One of the automatic stations, which was installed in May 8, 1955, in a region northwest of the Novosibirsk archipelago, operated without interruption for over a year and a half. It followed the drift of a large ice mass: first, to the northwest along the route of the *Fram*; then, in the middle of June 1956, it took a sharp turn to the south at the 84th parallel, and eventually ended up at about 81°N. In 1956, drifting automatic radiometeorological stations made their first appearance, with Alekseyev himself setting up two prototypes of his new DARMS in the vicinity of drifting station North Pole-4.

In April of 1957, the Soviets launched an impressive High Latitude Air Expedition, in which 270 scientists, engineers, and pilots took part, along with 17 aircraft. The drifting station North Pole-4 was evacuated and a new drifting station, North Pole-7, was established. In addition, North Pole-6 was resupplied and some of the personnel were relieved. The Expedition carried out numerous meteorological and hydrological observations, and also put 26 automatic stations out on the ice of the Arctic Basin. Eleven of these were automatic radio-beacons, and 15 were stations of the new DARMS type, which transmitted meteorological data in addition to position signals. Two of the DARMS were set up on North Pole-6 and North Pole-7 so that DARMS data could be checked against conventional observations. An attempt was made to place the other DARMS in regions where meteorological observations had never before been made.
Up until this time, the automatic stations had usually been installed in the spring. In 1958, 1959, and 1961, however, the DARMS and radio-beacons were for the first time set out in the fall months. This was done in order to obtain some data on ice movements in the winter period, when the dark Arctic night makes aerial reconnaissance impossible. Spring installations also continued as 11 Alekseyev radio-beacons and 10 DARMS were set out in the early months of 1958; and the High Latitude Aerial Expedition of 1959, with a 19-man party and two Li-2 aircraft, set up 26 DARMS in widely scattered areas of the Arctic Basin, from Franz Josef Land east to 170°W, including ten installations above 80°N and one right at the North Pole. This latter expedition also resupplied North Pole-6, evacuated North Pole-7, and established a new drifting station, North Pole-8.

In 1960, the Soviet High Latitude Expedition "Sever-12" set out to explore and research the regions encompassing the northernmost islands and peripheral seas of the Soviet Arctic. Part of its task involved the installation of drifting automatic radiometeorological stations at 15 points on the pack ice of the Laptev, Kara, Chukchi, and East Siberian Seas. North Pole-8 was resupplied and North Pole-9 established in that same year.

In the fall of 1961, the Soviets embarked on an unprecedented type of High Latitude Expedition, in that the nuclear icebreaker Lenin was used to set up a large manned drifting station, North Pole-10, and to deploy 15 DARMS along the southern edge of the permanent pack ice. A third major objective of the expedition was to check the performance of the Lenin in high latitudes under conditions of approaching winter and polar night.

By this time the Soviets had established a pattern of installing a relatively large contingent of automatic stations every year. The installations took place twice a year: during the spring months of March and April, and during September and October in the fall. In the former period, the automatic stations were put out on the ice by high-latitude air expeditions; in the latter period, the installations were performed by sea expeditions. Automatic stations were also put out on the drift ice from some of the transport ships navigating the Northern Sea Route. In general, efforts were made to locate the stations in Arctic Basin areas to which access was difficult and in regions either where interesting conditions were known to prevail
or from which regular data were required. Also, as a rule, one or two DARMS were installed on or near Soviet manned drifting stations, and the automatic stations were usually left operating when the manned drifting stations were abandoned.

Between 1953 and 1965, a total of 274 Alekseyev automatic stations were installed on the drifting ice of the Arctic Basin. Of these, 133 were radio-beacons and 141 were DARMS. The specific distribution is presented in Table 1 and illustrated in Figure 5.

The average operating life of the radio-beacons and DARMS was around 105 days. An exact breakdown of operational durability is given in Table 2. We see, for instance, that only 7 stations sent no signals at all or operated for less than a day. Fifty percent of the automatic drifting stations had an operating life of between 2 and 7 months. The least successful year for automatic stations, from the viewpoint of duration, was 1953. In that year, the average life span of automatic stations did not exceed 30 days, and the probable explanation for this is the early lack of expertise in the installation of the radio-beacons.

Another interesting statistic is that the automatic drifting stations installed in the fall months displayed a 40-percent greater operating durability than those set up in the spring months. This was due to the summer melting of the ice in the Arctic Basin in general and around the automatic stations in particular. The ice under the installed automatic stations melts considerably faster than the surrounding ice, since the station structure absorbs greater quantities of solar radiation. Once the ice under two of the three station supports melts or opens up, the vertical structure will either topple over or sink, and the automatic station will cease to operate. The Soviets do not, as a rule, recover (except for occasional test purposes) and reuse the Alekseyev radio-beacons and DARMS, which implies that they find it more practical to simply replace them.

In general, several interesting conclusions can be drawn from the Soviet experience with automatic drifting stations:

1. Cessations of station operation are not distributed uniformly over the period of a year, but rather, as a rule, the greatest number of station "deaths" occur during the summer period, and the least
Fig. 5 -- Installations of radio-beacons and DARMS during the period 1953-1965.
### Table 1

**DISTRIBUTION OF AUTOMATIC DRIFTING STATIONS IN THE ARCTIC BASIN FOR THE PERIOD 1953-1965**

<table>
<thead>
<tr>
<th>Automatic Stations</th>
<th>Peripheral Seas of the Soviet Arctic</th>
<th>Central Arctic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kara</td>
<td>Laptev</td>
<td>East Siberian</td>
</tr>
<tr>
<td>Radio-beacons</td>
<td>29</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
<td>DARMS</td>
<td>6</td>
<td>32</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>74</td>
<td>70</td>
</tr>
</tbody>
</table>

### Table 2

**LIFE SPAN OF AUTOMATIC DRIFTING STATIONS IN THE ARCTIC**

<table>
<thead>
<tr>
<th>Duration (days)</th>
<th>&lt; 1</th>
<th>1-10</th>
<th>11-20</th>
<th>21-40</th>
<th>41-60</th>
<th>61-100</th>
<th>101-150</th>
<th>&gt; 475</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of auto-</td>
<td>7</td>
<td>23</td>
<td>9</td>
<td>20</td>
<td>23</td>
<td>59</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>matic stations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration (days)</th>
<th>151-200</th>
<th>201-250</th>
<th>251-300</th>
<th>301-350</th>
<th>351-400</th>
<th>401-475</th>
<th>&gt; 475</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of auto-</td>
<td>34</td>
<td>20</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>matic stations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
number during the winter and spring periods. A mean distribution curve for automatic station losses is shown in Figure 6. The mean duration of the operation of the DARMS set up in the spring period is 3.5 to 4 months, while the mean duration for those set up in the fall months is 6 to 8 months. This difference in duration is apparently due to the fact that the DARMS set up in the fall operate during the fall/winter season when the Arctic ice cover is the most solid and the radiation/thermal factors are minimal. In general, it was determined that the duration of a DARMS drift was directly proportional to the ice thickness and the geographical latitude at the DARMS area of operation.

![Fig. 6](image-url)  
Fig. 6 -- Mean distribution of radio-beacon and DARMS losses in the course of a year.
2. Having data on the actual drift of the automatic stations and the computed movement of the ice by isobars, it is possible to determine the speed and direction of sea currents. To illustrate this last point, let us look at a situation in 1964, when several automatic drifting stations were operating in the Laptev Sea, slightly to the east of Severnaya Zemlya. By taking the difference between the vectors of the actual drift of the DARMS and those of the computed isobaric drift, the direction and speed of the currents were determined. Figure 7 shows that the direction of the currents, computed according to the actual and isobaric drifts of the ice, agrees with observed sea currents. Shown on the same map are directions of sea currents which were computed by an analogous method according to data from automatic stations drifting in that area from 1957 through 1963. Such a composite map gives a fairly

Fig. 7 -- Map of the sea currents east of Severnaya Zemlya. 1. Automatic station index and period of operation. 2. Directions of currents, calculated with the help of automatic drifting stations. 3. Directions of currents, previously observed.
complete picture of the direction of currents in the western part of the Laptev Sea. Consequently, having calculated the isobaric ice drift and knowing the actual drift from displacements of the automatic stations, it becomes possible to determine the nature of the sea currents.

3. Data obtained from DARMS can be used as a check on conventional meteorological observations performed on manned drifting stations and during high-latitude air expeditions.

By the beginning of 1967, the aggregate number of automatic drifting stations deployed in the Arctic Basin by the Soviets had risen to 291 (see Figure 8). They had drifted for more than 220,000 miles, and coastal stations

![Deployment of Drifting Automatic Stations in the Arctic Basin from 1953 through 1966](image)

**Fig. 8**
Deployment of Drifting Automatic Stations in the Arctic Basin from 1953 through 1966 (1) DARMS sending both meteorological and ice-drift data; (2) radio-beacons sending only ice-drift data.
had taken 170,000 position bearings on them. In addition, the DARMS had sent in over 32,000 meteorological data reports.

By 1968, the aggregate number of deployed automatic drifting stations was 325. Since then, with the Soviets continuing to deploy 20-25 DARMS and radio-beacons annually, the aggregate number has probably exceeded 400. The Arctic and Antarctic Institute envisions a continually improving year-round network of automatic drifting stations in the Arctic, with data-gathering DARMS deployed in the higher latitudes and the more expendable radio-beacons deployed along the edge of the permanent ice pack (primarily to provide information about ice movements in this region).

**DARMS DATA AND THEIR ACCURACY**

The DARMS instrument block measures the following variables: air temperature, atmospheric pressure, wind direction, and wind speed. Air temperatures are reported over a 90° range (from -55°C to +35°C), and atmospheric pressure is measured over a range extending from 950 to 1050 millibars. The DARMS determines wind direction to the nearest 22.5° increment of arc, and measures wind speed over a range of 1.5 to 25 meters per second. The data transmitted on wind speed and direction are automatically averaged by the DARMS for each 8- to 10-minute interval. The large vane of the instrument block turns the unit around a vertical axis in the direction of the wind. The two smaller vanes are used for determining the wind speed.

In order to test the accuracy and reliability of the DARMS sensors, controlled comparison studies were performed on North Pole-9, on North Pole-14, on Dickson Island, and at an experimental base of the Arctic and Antarctic Institute. After nearly 600 observations, the following determinations were made.

The DARMS sensor that measures atmospheric pressure had a 57% concurrence rate with the control barometer within the limits of ± 1 mb, and 81% within the limits of ± 2 mb. Pressure sensor readings whose deviation exceeded ± 3 mb comprised 12% of the total number of compared data.
The air temperature sensor of the DARMS (a bimetallic plate) proved to be a somewhat poorer performer. Only 30% of all the observations fell within the limits of ± 1°, and 65% within the limits of ± 2°. Temperature sensor readings whose deviation exceeded ± 3° comprised 21% of the total number of observations.

The DARMS wind speed sensor (an anemometer with two perpendicular vanes connected to torsion springs) had the highest concurrence rate where 79% of all the observations fell within the limits of ± 1 m/sec and 93% within the limits of ± 2 m/sec. The wind direction (measured with a magnetic compass card) had a concurrence rate of 67% within the limits of ± 20° and 80% within the limits of ± 30°.

The testing uncovered a number of technological and manufacturing defects in the DARMS instrument block. It was indicated, however, that a slight amount of modernization would significantly improve the accuracy of the meteorological sensor units.

THE NEW DARMS AND FUTURE CAPABILITIES

The Arctic and Antarctic Institute has been developing a new version of the DARMS, and by all indications it should be ready for deployment in about one year. Soviet scientists have learned much from the many years of experience with the present DARMS and have applied this knowledge to the development of the new DARMS, which promises to be a good one.

From what little information is available about the new DARMS, it appears that the entire unit will be supported by a single rod sunk through the ice (in contrast to the present model, which is supported by a center shaft and three prongs). The single-rod design will serve to give the new DARMS a much greater capability to withstand ice breakup.

The Soviets have indicated that the new DARMS will be tracked and interrogated by both shore stations and satellites. A satellite link will, of course, give the new DARMS a greater operating range. It will also result in more accurate, and consequently more useful, position data from the DARMS.

The Soviets have also announced that the new DARMS will be able to hold more sensors and transmit greater amounts of data, both meteorological
and oceanographic. Due to its improved capabilities which will allow the new DARMS to report on water temperature, ice temperature, and atmospheric humidity, the new model is sometimes referred to as the DARGMS (a contraction of the Russian for Drifting Automatic Radio Hydrometeorological Station). In addition to these added features, the sensing accuracy of the new DARMS will be much improved over present capabilities.

BIBLIOGRAPHY


In April of 1970, the Defence Research Establishment Pacific (DREP) installed a field of "Sono-Drift-Buoys" in Viscount Melville Sound and M'Clure Strait. The buoys, constructed at DREP, were intended for measuring ice drift and underwater acoustic ambient noise.

CONSTRUCTION

The main casing of the buoys was an aluminum tube 15 feet in length and 3.5 inches in diameter which contained the battery pack (Alkaline D cells) and electronics units. The electronics rack contained a preamplifier, a postamplifier, a transmitter, a duplexer, a receiver, a decoder, and a timer. The antenna was supported on top of the buoy by a four-foot mast, and the hydrophone was clipped to a tubular mounting affixed to the bottom of the buoy.

The buoys are installed in holes drilled through the ice. Once installed, the receiver operated continuously. When a properly coded signal was detected by the receiver and decoder, the timer was activated. Power was switched on to the amplifiers and the transmitter. Acoustic signals detected by the hydrophone were amplified and transmitted. After ten minutes, the timer switched off the amplifier and transmitter. These remain off until the buoy is triggered once again.

An overflying aircraft was used to collect the data. When the buoy had been triggered by transmission of the appropriately coded signal, the aircraft was flown to the buoy using the aircraft's radio direction finding equipment as a homing device. At the same time, information transmitted by the buoy was recorded on magnetic tape in the aircraft. When the aircraft was on top of the buoy, a photograph was taken of the aircraft's radar.
scope. This photograph was later compared with a map of the area to locate accurately the buoy position.

RESULTS

Buoy failure was 33% by the end of June, 60% by the middle of August, and 80% by the middle of September when the last check was made. Those buoys mounted in polar ice lasted significantly longer than those mounted in annual ice. The greatest losses occurred during the period of small-scale ice movement while there was still ten-tenths ice cover, before large-scale movement of the ice occurred.

Ice drift in Viscount Melville Sound displayed no regular pattern during the period of the experiment. A generally westward movement was apparent in M'Clure Strait. Ambient noise measurements agreed well with other measurements made in the area at other times of the year.
EXPERIMENTAL ARCTIC DATA BUOY

by

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Applied Physics Laboratory
University of Washington

BACKGROUND

The National Data Buoy Project (NDBP) is conducting the research, development, tests, and evaluation necessary to implement national data buoy systems for the purpose of collecting accurate synoptic and environmental information of national interest and providing it to various users. The scope of the NDBP interest includes the Arctic and the achievement of high reliability sensors and data collection systems for use in the environment.

The Applied Physics Laboratory is undertaking the development of an Experimental Arctic Data Buoy for the NDBP which will begin to provide the information necessary for the NDBP to achieve its goals relative to the Arctic. This effort is considered a preliminary step in this mission. It will involve fabrication of a system to measure atmospheric pressure and temperature and will utilize an Interrogation, Recording, and Location System (IRLS) for location and data telemetry. The system will be deployed adjacent to Fletcher's Ice Island (T-3) in the fall of 1971 for a six-month operational evaluation phase. Of primary interest will be the utility of the basic configuration relative to its transportability, ease of installation, and reliability; and the reliability and location accuracy of IRLS.

GENERAL DESCRIPTION

The Arctic Data Buoy is intended for prolonged periods of unattended operation on the drifting pack ice. It must therefore be able to withstand the environmental extremes found in the Arctic and must be relatively safe
from permanent degradation caused by ice movement, surface melting, ice break-up, and refreezing. In addition, it must be easily transported to location by small aircraft and easily and quickly installed for operation by small crews.

These requirements have led to a basic buoy configuration which is relatively small and light and which, when installed, is not dependent upon the ice for physical support. It can operate in either a free-floating or a through-ice situation and is capable of undergoing transitions between these states without being damaged or degraded.

The experimental buoy will consist of (1) a main body containing the electronics, power supply, and pressure sensor and (2) an antenna mast supporting the IRLS antenna and the temperature sensor. When assembled, the buoy will extend about 30 feet and weigh about 225 pounds. Figure 1 depicts the buoy installed in the pack ice.

**Main Body**

The body will be cylindrical (a spar buoy) and will provide the buoyancy and structural support for the assembly. An overall body length of 20 feet, with 16 feet of submergence, will ensure that both air-ice and water-ice interfaces are penetrated by the body. The outside body diameter will be 7.9 inches, providing about 21 pounds of buoyancy per submerged foot of length. Batteries and electronics will be housed in watertight containers and located in the bottom of the body for warmth and to provide self-righting moment for the buoy. They will be thermally closely coupled to the outer shell and maintained at an almost constant temperature by the surrounding water. The battery and electronics package will be removable, while the body is frozen in the ice. Commercially available polyethylene pipe will be used to fabricate the body pieces. They will be made in 10-foot sections to facilitate handling and transportation. Aluminum joint bands and end caps will be used to assemble the body. Polyethylene has a low thermal conductivity, and vertical heat transfer through the body will be minimized by filling the void spaces with closed-cell foam which will also provide emergency flotation for the buoy.
Figure 1. Experimental Arctic Data Buoy--Conceptual Drawing
Antenna Mast

The mast will carry the antenna and temperature sensor (and, in the final design, other meteorological sensors). An unguyed aluminum tube 2 to 3 inches in diameter will support the antenna about 13 feet above the normal water surface. Electrical wiring will be carried internally through the tube. The antenna will have a nonmetallic cover to protect the transmitting elements from the effects of ice deposits.

Electronics and Power

The electronics will consist of an IRLS Balloon Interrogation Package (BIP) adapted for Arctic Data Buoy application together with interface electronics to match sensor outputs to encoder requirements. Mercury cell batteries having a 2600-watt-hour capacity will provide sufficient power for a one-year operational period. (IRLS requirements for one year will be about 1400 watt-hours.)

Test Data

In normal operation where IRLS ground platform position is being determined, there are two or more communications between the satellite and the ground platform during each orbit of the satellite. Using the BIP, it is possible during each communication to transmit seven data words. Data word length is seven bits, providing resolution of one part in 128 for each quantity digitized.

Sensors

Selection of atmospheric pressure and temperature sensors will be based upon the results of a survey of available sensors and recommendations of the Atmospheric Sciences Department. A primary problem is expected to be icing of the temperature sensors, radiation shield, and pressure sensor access port.
**Data Buoy Handling and Installation**

The experimental buoy assembly will be transportable in six pieces: antenna, antenna mast, battery pack, electronics and sensors, and two body sections. The largest pieces will be the 10-foot body sections, and the heaviest piece will be the battery pack of about 80 pounds.

Installation of the buoy through the ice will be facilitated by using a portable tripod. All electrical and mechanical connections will be designed for fast assembly. If necessary, a freezing retardant will be added to the water in the ice hole to allow sufficient time to accomplish the assembly and check-out. It is estimated that three men should be able to complete the installation in one hour including an allowance of one-half hour to drill an 8-inch diameter hole through the ice.

**POTENTIAL USES**

The basic spar buoy configuration could be advantageous in a wide range of Arctic applications. This is particularly true where surface ice conditions preclude the use of systems supported by the ice and/or where a hole through the ice will be required anyway for installation of oceanographic sensors or for other purposes. Also, because the power supplies and electronics are immersed in the relatively warm and constant temperature sea water, heating is not required and operational variations caused by thermal changes are much reduced. Calibrations can be accomplished in the Laboratory at temperatures within a degree or so of the operational temperature which will exist in the field.

The buoy offers a good platform for oceanographic and meteorological sensors, causing only small interferences with the ice-water and ice-atmosphere interfaces. By changing the number and/or length of the body sections employed, the payload can be configured to the application and the total buoyancy can be varied. One application now under design will utilize a digital magnetic tape recorder to log oceanographic data throughout a one-month period. In this case about 50 pounds of sealed, rechargeable, lead-acid batteries providing about 500 watt-hours of energy will be utilized.
Buoy retrieval from thick ice is possible using a hot water or steam ice-melting device with an annular cutting head. In certain cases it may be more desirable to merely remove the sensors and electronics and leave the body in the ice.

IRLS

Two of the primary problems associated with remote, unmanned Arctic data stations are location and data telemetry. The IRLS has capability in both areas; it is fully operational; and hardware exists which is readily adapted to remote platform use.

Location is accomplished during a given satellite orbit by means of two range measurements made between the satellite and the ground platform being located. The position of the satellite at each time of ranging is computed from the satellite ephemeris. The platform then can be located on the surfaces of each of two spheres with known centers and known radii. Since the platform is on the surface of the earth, it must be located where the two spheres intersect with the surface of the earth and with each other. There are, therefore, at most two points where the platform can be. This ambiguity is usually resolved by one of the two points being at an impossible or improbable location.

The design goal for absolute location accuracy of IRLS is ± 1.5 km. This goal has been achieved in practice, but only under good conditions with accurate ephemeris data. Errors more generally range upward from 2 km, dependent upon time since ephemeris update and other factors. It seems that, with reasonable attention on the part of IRLS operators at the ground control station, an accuracy of about ± 2 km can be expected from IRLS.

The accuracy of locating one ground platform relative to another in the same general vicinity should, of course, be better than the location accuracy for any one platform. Apparently this "relative location" mode of operation of IRLS has not been analyzed in detail to date. In theory, errors in the relative position of two platforms should be a function of platform separation with minimum error occurring for adjacent platforms where all variables external to the platforms are common to both platforms.
In 1969, two platforms operating from known locations and separated by about 900 miles exhibited absolute location errors that ranged from 0.9 to 20.5 km with 90 percent being less than 14 km. This sample includes only cases in which both platforms were located during a given satellite orbital pass and totals nearly 150 separate locations. Adjusting the location error magnitudes of one platform by the error magnitudes of the second platform improves the location errors to less than 12 km with 90 percent being less than 5 km. Figure 2 indicates the systematic nature of the location errors for the two platforms. From these observations it seems reasonable to expect that the relative location accuracy of IRLS for platforms with small separations would be better than \( \pm 1 \) km. (Over half of the corrected errors noted above were less than 1 km.)

Data telemetry is accomplished during each satellite interrogation of the ground platform. The number of words of data which can be transmitted depends upon the type of platform utilized. The normal ground platform data block includes 28 separate 7-bit binary data words. The BIP platform transmits only 7 such data words per interrogation. A 7-bit word allows resolution of one part in 128.

Because IRLS location requires at least two successful platform interrogations during a satellite pass, there are generally more than two interrogations scheduled per pass for each platform to be located. It is therefore generally possible to transmit two or more data blocks per satellite pass. The NIMBUS satellite orbit is near polar (10 degree cant) with a period of about 110 minutes. Interrogation range is up to 2000 km, so that interrogations in the Arctic will be possible on perhaps one-half or more of the orbits depending upon the geographical location of the ground platform.

As far as AIDJEX application goes, IRLS has several disadvantages besides the limited location accuracy and data telemetry rates discussed above. Obviously, measurements can be only quasi-synoptic because only one platform can be interrogated at a time. In addition, every interrogation attempt is not successful and interrogations are not possible on every orbit. Data sampling, therefore, cannot be highly controlled and "holes" may occur in sampling.
The future of IRLS is rather uncertain at this time. It is anticipated that IRLS will remain operational on the present satellite NIMBUS IV for perhaps another year. IRLS, however, is not included in NIMBUS V, and its presence in later satellites is still questionable, depending to some extent at least upon user demand. Therefore, following the demise of the present satellite system, a gap of indeterminate length will exist in IRLS operations.
A REMOTE AUTOMATIC MULTIPURPOSE STATION (RAMS)

by

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NEED FOR UNMANNED STATIONS

Delco Electronics Program

Delco Electronics has carried out a program of applied underwater acoustic research in the Arctic Ocean since 1962. This effort has centered on parameters affecting sonar performance and design. Included in these parameters are statistics and levels of ambient noise and correlation with environmental factors, ambient noise anisotropy and its effect on array performance, and acoustic transmission loss and propagation characteristics. Experiments have been carried out from six different floe stations, ice islands T-3 and ARLIS II, and a number of short-term camps on the ice. In the process of performing these experiments, the potential value of a simple unmanned telemetry station for gathering various types of data became apparent. An unmanned station incorporating a telemetry link was utilized by Delco Electronics as early as 1962 [1], and several applications of an unmanned acoustic data gathering station using magnetic tape data storage have been made since that time [2, 3]. A study was also made of the selection of sites for unmanned detection of underwater signals in the Arctic [4] providing information on ice motion, ice characteristics, and unmanned station design requirements.

A number of recent developments have given particular emphasis to the need for unmanned stations.

1970 Field Experiment

Recent field experiments, especially in the area of underwater acoustics [5], have indicated a wide synoptic variation in the oceanographic
characteristics of the Arctic and point to the need for an economical yet effective means of gathering data simultaneously from many widely separated locations. Simple remote automatic multipurpose stations appear to be an answer to this need. Such stations would also extend the data gathering capabilities over a large part of the year instead of concentrating them in the early spring months.

**Soviet Experience**

Since 1953, the Soviets have successfully employed drifting automatic stations (DARMS) in the Arctic Basin for the collection of meteorological and oceanographic data. Two hundred seventy-four of these expendable, long-range radio buoys were deployed from 1953 through 1965. The U.S., on the other hand, has never employed such unmanned stations in the Arctic except on a small scale as reported in References [1], [2], and [3].

The Soviet DARMS is basically an economical, easily deployed, battery-operated radio station employing a guyed vertical antenna about 40 feet high. Ranges of up to about 700 nautical miles have been attained using 40 watts in the medium frequency range of 475 to 700 kHz. Batteries and timing circuits are submerged in the near-constant temperature water. A low-duty cycle is used to give a useful battery life extending over several months. Shore monitoring stations are used to triangulate each buoy for tracking purposes and for the regular collection of telemetered data. Instruments for sensing include a thermometer, anemometer, barometer, current meter, and other specialized meteorological apparatus.

While it is not proposed that a "Chinese copy" be made of DARMS, the available reports on this equipment have been studied to provide a point of departure in the development that will employ modern radio techniques and transistor circuitry. There is no point in duplicating the errors of the early Russian efforts.
RAMS CONCEPT

Design Approach

The block diagram of Figure 1 shows the design approach that Delco Electronics feels will be successful. This approach incorporates the following into a simple, universal telemetry station: digital memory-to-transmitter interface electronics, modular digital memory, modular sensor package, and modular power source. The basic elements of the system, as currently contemplated, are discussed briefly in the following paragraphs. As the design progresses, further tradeoff analyses will be made to optimize the various elements, and some design changes may be made.

Station Subsystem

The telemetry station includes an antenna structure, 100-watt high-frequency transmitter, and a timer (or command receiver*) for triggering the transmitter. The interface electronics provide means for interrogating the digital memory and modulating the carrier frequency with the digital message content. These electronics will interrogate the memory a number of times to provide message redundancy for error correcting and will clear the memory at completion of interrogation.

The digital memory will be modular to enable handling various amounts of data as required by the particular sensor package utilized. (More than one package could be used if a station is used for multiple purposes.) The memory will probably utilize MOS shift registers, although simple core memories can be considered if greater data storage is desired. A fixed portion of the message will be preserved in the memory for synchronization and identification purposes.

The power source will also be modular to span the range of energy storage required for different sensor packages, message lengths, and transmission cycles. Batteries, if used, would be submerged to keep their

*An applicable command receiver was developed in an earlier program and reported in Reference [6].
temperature at 28°F. A study of candidate batteries for low temperature application has been made together with some experimental work under realistic temperatures and load cycles. Analysis of the test data has not yet been completed, but low temperature mercury cells and sealed zinc-oxygen cells are being considered as candidates. Providing a constant supply voltage in the face of continually decreasing voltage typical of discharging batteries is another problem that was considered. Clipping the voltage and dropping the excess energy across a resistor, as is commonly done, is extremely inefficient. A simple, efficient solid-state device for supplying constant voltage has been investigated at Delco Electronics [7] and appears applicable to the task.

Perhaps a more attractive power supply package is a propane-fueled thermoelectric cell. These are highly reliable; they produce heat which could be used in a suitable shelter such as a small wanigan to keep batteries and electronic components warm; and they provide much higher average power than batteries.

A wide range of sensor packages can be considered for use with the system. Specialized packages can be designed by individual investigators if so desired as long as the interface requirements are met. A number of types of sensor packages than can be considered are listed below:

1) Acoustic data
   • ambient noise levels
   • propagation data
   • associated oceanographic and/or meteorological data influencing noise (e.g., wind, temperature, currents, BT's)

2) Meteorological
   • temperature
   • wind
   • barometric pressure
   • cloud cover

3) Oceanographic
   • current
   • water temperatures
4) Ice Physics
   - drift
   - strain
   - relative position

5) Approximate location (i.e., beacon or OMEGA retransmit)
6) Precise location (i.e., transit satellite retransmit)
7) Surveillance (acoustic)

**Special Design Considerations**

DARMS uses a ground wave propagation at medium frequency and attains a maximum of less than 700 nautical miles effective range with a mean range of 300 nautical miles. Since it has been used mainly to monitor conditions along the Northern Sea Route, these ranges to shore receivers have been satisfactory for their purposes. To extend the effective antenna height at MF, the Soviets utilize capacitive top loading which requires guying the antenna.

It would be desirable in the RAMS application to attain much longer ranges for several reasons. In the first place, the available U.S. shore receiving sites are limited in the Arctic. Candidate U.S. sites are T-3, Barrow, Adak, Thule, and Iceland. Other possible sites are Alert, Nord, Spitsbergen, and Norway. None of these sites is within reliable MF ground wave range of the eastern (Russian) side of the Arctic, yet this is an area in which almost no U.S. measurements have been made on the ice.

Much longer ranges could be realized through HF sky wave transmission but at some sacrifice of signal availability. Also, an HF vertical antenna of 1/4 wavelength could probably be supported satisfactorily without guys, since it would not have to be top-loaded. For these reasons, it is believed that the HF approach is best for the first model. If it is determined later that the more continuous but shorter range MF system would also be desired for certain applications where acoustic noise is unimportant, it would be a relatively simple task to change the antenna and transmitter.

The system will be designed so that stations can be deployed readily with the Naval Arctic Research Laboratory R4D. Any special requirements for deployment from icebreakers, helicopters, and submarines will also be considered during design so that the system will be completely flexible.
Some attrition must be expected with systems of this type due to ice activity, excessive melting, breakdowns, etc., so that particular attention will be given to simplicity and low cost. Sensor packages would vary in cost depending on complexity, but efforts would be made to keep these in the same cost range. An attractive housing for the station would be one of the prefabricated 8'x8' wanigans that NARL has developed. Such a building could hold enough propane bottles for a one-year fuel supply for a 7-watt TE cell.

Knowledge of station position is necessary to associate the data taken with a particular locale, to relocate the station for potential servicing or recovery, and to monitor ice drift. Conventional radio direction finding techniques could be used for gross localization. However, a retransmission of OMEGA or processed Transit satellite signals is a more attractive possibility. It is understood that the U.S. Coast Guard has given a contract for the development of an open-ocean buoy system of OMEGA retransmission. The results could be applied to RAMS. Delco Electronics has completed the design of—and is constructing—a low-cost, single frequency Transit satellite system that could be used for RAMS and other navigation requirements where low cost, low power, and portability are important considerations.

References


3. B. M. Buck, A. W. Magnuson, and D. A. Chalfant, Underwater Acoustic Measurements at Central Arctic Floe Ice and Ice Island Stations—Spring 1970 (U), in preparation (C).

5. B. M. Buck paper being prepared for JUA issue on Arctic.


POSITIONING
THE NAVIGATION OF FLETCHER'S ICE ISLAND (T-3)

by

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CELESTIAL NAVIGATION AT T-3

Prior to 1967, navigation of ice stations by the Lamont group was entirely by observations of natural celestial bodies with a bubble-level theodolite. A navigational fix consists of at least three sights, either on three different bodies or on a single body at three different times. During the winter, the angles to three stars can be determined in rapid succession for a fix. During the summer, however, at high latitudes, the only available body is the sun, which must be sighted at three successive times, usually about two hours apart. Until recently, the data were reduced using the Nautical Almanac and the H.O. 214 Sight Reduction Tables. However, all T-3 celestial sights have now been recomputed with three computer reduction programs which provide more accuracy than the older method.

The programs are written in Fortran for an IBM 1130 digital computer with 16K word core storage, card reader/punch, and a disk storage system. With small changes the programs should be compatible with other computers. Program listings, without control cards, are available from Lamont.

Over 2400 celestial fixes were used in the preparation of the T-3 drift track from 1962 through 1970. Each fix, consisting of three or more lines of position, required checking, and often recomputation. Because the observational methods afforded more precision than that available by reduction using the Nautical Almanac, and in order to achieve some measure of
uniformity in the work of numerous navigators, the fixes were recalculated by computer.

Three steps are entailed in determining a fix. The first involves reducing the observations, the second requires the calculation of the celestial coordinates of the bodies observed, and the third consists of finding that geographic position which satisfies the observations. The programs are written so that the first and third steps are lumped together, and the second step is performed first.

Celestial coordinates are computed by two programs, one for the sun and stars, the second for the moon. The planets are not programmed, as their motions are considerably more complex than the other bodies. However, a provision was made so that planet data could be used with somewhat diminished accuracy. Program EDOC (Ephemeris Data on Cards) computes the solar or stellar Greenwich Hour Angle, declination, horizontal parallax, and semi-diameter, while LUNE (lunar Ephemeris) does the same for the moon. The coordinates for the sun in the hour angle system are determined trigonometrically transforming the solar ecliptic latitude and longitude, computed from the Newcomb theory. Brown's theory is used in a similar fashion for the moon. In these theories, the latitude, longitude, and radius vector are described by generating functions with numerous additional terms stemming from the perturbations of the planets. The formulae employed are given by Woolard (1953). In practice, the maximum errors in the computed coordinates should be less than 3° of arc (0.05 nautical miles). Star coordinates are determined by updating the right ascension system coordinates of navigational stars at epoch 1950.0, as determined from the Smithsonian Astrophysical Observatory Star Catalog (1966). The method of updating is given in the Explanatory Supplement to the American Ephemeris and Nautical Almanac of the Almanac Office (1961).

A punch card is prepared for each observation, giving Greenwich date and time of observation, a code number for the body observed, the altitude and relative azimuth of the body, the air temperature and barometric pressure, the approximate position, and the body name. The observation cards, each followed by a blank card, are fed into the computer, the proper coordinates are computed by EDOC or LUNE, and the results are punched on
the blank. The observation cards with their coordinate data are then grouped into fixes (up to six observations per fix), terminated by another blank, and processed by a third program called CELPS (Celestial Positions).

Program CELPS computes the following:

a) The correction for atmospheric refraction to be applied to the observed altitude, determined from the Pulkova formulation;

b) The latitude and longitude of the intersection of every two lines of position;

c) The latitude and longitude of the center of the circle inscribed into each triangle determined by three lines of position, along with the radius of that circle in nautical miles;

d) The perpendicular distance from each line of position to the center of the smallest inscribed circle, in nautical miles;

e) The latitude and longitude determined by a least squares solution of all lines of position;

f) The azimuth of the zero-line of the theodolite horizontal circle referenced to true north, for each line, calculated from the center position of the smallest inscribed circle; and

g) The average time of all intersections and triangles determined from the original times of the observations comprising them, and the duration of the fix in hours.

The results are printed out (Figure 1), and the position associated with the smallest circle of error—assumed to be the best position—is punched onto the final blank card as data to be used in subsequent programs. Data from planets, or any other body for that matter, can be used by obtaining the hour angle and declination from the Nautical Almanac or American Ephemeris and entering these numbers on a blank card following that particular observation card. This method can also be used for visible earth satellites if their coordinates are known. If only one observation is available, the assumed position is used to compute the theodolite zero-line azimuth.

Several merits and limitations of the CELPS program should be noted. Two generating functions for the water vapor pressure as a function of temperature are used in the refraction formulae, permitting corrections
CELESTIAL NAVIGATION PROGRAM
LAMONT GEOLOGICAL OBSERVATORY - ARCTIC SECTION

LOP DAY MO YEAR HOUR ALTITUDE DEC GHA AZIMUTH(T-3) AZ(BODY) BODY ERROR
1 20 3 1970 628 35-42.455 38-44.761 335-17.201 78-27.645 56.9 36 VEGA -0.00
2 20 3 1970 631 40-2.776 45-10.036 324-57.012 78-27.243 27.7 20 DENE B 0.00
3 20 3 1970 634 53-22.019 49-27.391 69-9.760 78-25.479 129.1 12 ALKAID 0.01
4 20 3 1970 637 46-20.954 45-58.606 197-54.622 78-26.007 269.4 19 CAPELLA -0.03

INTERSECTION LATITUDE LONGITUDE TIME
1 AND 2 84-8.736 -114-36.375 629
2 AND 3 84-8.711 -114-36.210 631
3 AND 4 84-8.642 -114-35.773 632
4 AND 3 84-8.723 -114-36.116 632
5 AND 4 84-8.704 -114-35.779 634
6 AND 4 84-8.764 -114-35.785 635

TRIANGLE INTERSECTIONS LATITUDE LONGITUDE RADIUS TIME
1 1 2 4 84-8.721 -114-36.205 0.005 631
2 1 3 5 84-8.695 -114-35.929 0.015 632
3 2 3 6 84-8.709 -114-35.972 0.019 633
4 4 5 6 84-8.727 -114-35.913 0.013 634

RESULTS AND AVERAGES
LINES DAY MO YEAR HOUR LATITUDE LONGITUDE AZIMUTH RE
4 20 3 1970 632 84-8.72 -114-36.21 78.442 0.0
LEAST SQUARES POSITION
84-8.71 -114-35.98

CELESTIAL NAVIGATION CALCULATION SHEET
Lamont Geological Observatory Fix 76 Sheet 1

<table>
<thead>
<tr>
<th>DATA</th>
<th>Station</th>
<th>T-3</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date 20 Mar 70</td>
<td>Observer A</td>
<td>Gilt</td>
<td>Seeing good fair</td>
</tr>
<tr>
<td>Celestial Body Vega</td>
<td>No 36</td>
<td>Air Temp: -43°F</td>
<td></td>
</tr>
<tr>
<td>Forward vertical circle</td>
<td>180.00°</td>
<td>Zenith Angle</td>
<td>D.R. Lat. 84.1°N D.R. Long 114.6°W</td>
</tr>
<tr>
<td>Reverse vertical circle</td>
<td>180.00°</td>
<td>Bearng of Reference Line</td>
<td>North East</td>
</tr>
<tr>
<td>Average Vertical circle</td>
<td>180.00°</td>
<td>Calculated by</td>
<td></td>
</tr>
<tr>
<td>Chronom corr</td>
<td></td>
<td>Checked by</td>
<td></td>
</tr>
<tr>
<td>GMT</td>
<td>06°27'34&quot;</td>
<td>RecHECKED BY</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 1
over a very broad range of temperatures (-75° to +40°C). The program is written for the northern hemisphere; slight alterations might be required for observations south of the equator. Finally, the instrumental height above sealevel $H$ is set at 5 meters, but should be changed if observation altitudes are appreciably different.

Six subroutines are used by these programs. Given the sine and cosine of an angle, QUAD gives the angle in the range 0 to $2\pi$. List element UPR is the units per radian, equal to 57.2957795131 if the result ANGLE is desired in degrees. JULDT converts the civil calendar date and Greenwich Mean Time to various forms of Julian time. TJ is days after $0000Z$ January 0, 1900, a convenient form for handling data collected over a broad time span, TJA is referenced to the beginning of the Julian calendar, and TJC is the fraction of the current Julian century, used in the astronomical generating functions. Subroutine TIME converts any of the aforementioned times back to civil date and Greenwich Mean Time. INLOP determines the intersection of the lines of position and the center and radius of the inscribed circles, while XYC and PFXY are discussed in the next section.

Together, these programs offer a convenient way to obtain position and azimuth information without the necessity of mastering celestial navigation, at least beyond the point of obtaining correct sights on identifiable bodies.

U. S. NAVY NAVIGATION SATELLITE SYSTEM ON T-3

On April 15, 1967, a set of AN/SRN-9 integral Doppler equipment was installed on T-3 by K. Hunkins and J. Hall and has continued to function well to the present. This system utilizes the Transit satellites which transmit orbital information and constant-frequency carriers, so that a Doppler receiver and computer aboard the ice station allow one to obtain an accurate fix at the time of the satellite's pass above the horizon. The system has two distinct advantages over celestial navigation with natural bodies. First, the system is independent of cloud cover; and second,
many more fixes are available since twenty to thirty passes per day may be obtained in high latitudes.

The principles of the satellite system are explained by Guier (1966). Experiences at sea are related by Talwani (1966) and Talwani et al. (1966). In an accuracy test in Iceland while the ship was docked, 50 percent of the fixes obtained fell within 0.07 nautical mile of the mean position. On an ice station the position is probably determined with considerably better accuracy than this due to the high rate of fixing and the low drift rate. The accuracy of the satellite fixes is probably not greater than that of the celestial fixes, but the high density of fixes allows one to draw a smoothed curve. This is apparent in Figure 2, where both satellite and celestial fixes are plotted for October, 1970, in terms of latitude and longitude. The increased density of the satellite data makes it possible to draw a drift curve with high reliability.

The system as presently operated on T-3 consists of an AN/SRN-9 set built partially at Lamont and partially by Magnavox. The Doppler frequency and orbital parameter data from the satellite are printed out in real time both on a digital printer and a paper tape punch. The punched paper tape is fed into a PDP-8/S general-purpose digital computer on the station to obtain a fix for operational purposes. For refined reduction, all tapes are returned to Lamont and reduced on an IBM 1130 computer which provides more accuracy.

A complete drift track for T-3, utilizing both celestial and satellite data is presented in Figure 3. Some statistics of the drift track are given in Table I. The net distance refers to the straight-line distance between the first and last fix of the month. Meandering coefficients are the ratio of net to total distance travelled and the reciprocal. The actual fixes are interpolated to produce a magnetic tape containing hourly position data. The interpolation procedure uses a computer program described in the next section.
T-3 NAVIGATION FOR OCTOBER 1970

FIGURE 2
INTERPOLATED DRIFT TRACK - FLETCHER'S ICE ISLAND (T-3)

MAY 1962 TO JAN 1971

FIGURE 3
<table>
<thead>
<tr>
<th>Time Mo Year</th>
<th>Monthly Distance (NM)</th>
<th>Meandering Coefficients</th>
<th>Yearly Distance Total Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net</td>
<td>Tot</td>
<td>Cum</td>
</tr>
<tr>
<td>5 1962</td>
<td>55.02</td>
<td>77.80</td>
<td>77.80</td>
</tr>
<tr>
<td>6 1962</td>
<td>76.41</td>
<td>125.51</td>
<td>203.31</td>
</tr>
<tr>
<td>7 1962</td>
<td>95.72</td>
<td>166.62</td>
<td>369.93</td>
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<td>8 1962</td>
<td>77.23</td>
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<td>524.91</td>
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<td>35.94</td>
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<td>1175.16</td>
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<td>1 1963</td>
<td>38.05</td>
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TOTAL DISTANCE AND DAILY TRAVEL OVER 3160 DAYS 10543.96 3.34
WIND DRIFT PROGRAM: WDP

An ice island, an unattached buoy, or any other drifting body moves in response to the winds and currents, which are themselves often wind produced. If position fixes are obtained infrequently, then frequent wind observations can help define the track of the body in the intervening periods. Such techniques have proved of great value in determining the drift of manned ice stations, and should prove useful in the future for the unmanned drifting scientific stations to be located and interrogated by earth satellite.

Nansen observed from the drift of the Fram that the ice drift was approximately 1/50 the wind speed in a direction 28-30° to the right of the wind (in the northern hemisphere). A computer program is presented that is based upon a similar assumption, except that the deviation angle and speed factor is calculated, and used with the observed winds to compute intermediate positions.

Program WDP (Wind Derived Positions) reads in a maximum of 2000 positions, followed by up to 5000 wind observations. Proceeding from fix to fix, it uses average winds between wind observations over the interval between fixes to compute not only the deviation angle and speed factor required, but also the ocean currents required if the ice responds to the wind according to Nansen's average values of 30° and 0.02. Printing these results, the program then calculates, for the time of each wind observation, the positions resulting from both the purely wind-derived-drift solution and the wind-plus-current solution. A card is punched at each calculation point giving the time and most probable position in a standard format compatible with the other reduction programs. The wind and current solution is used in place of the purely wind-derived solution whenever the calculated wind-speed factor exceeds 0.035 or falls below 0.0075, which is an indication that currents or the effects of winds acting at a distance are acting during periods of calm, or that the ice is restrained and cannot respond.

In addition to the most probable position, the program punches out the wind drift and current parameters and interval duration on the fix card ending each interval, making this information available for plotting theoretical currents, etc. Three new subroutines are called for by this program.
AWDP is an auxiliary subroutine of no special interest. XYC computes the cartesian coordinates of any point with latitude SLA and longitude SL0 on a north polar stereographic projection, such that the ordinate is zero along the meridian \((UMAX + UMIN)/2\). The coordinates are expressed in nautical miles, and angles in radians. PFXY converts these coordinates back to degrees and minutes of latitude and longitude.

In all programs, negative latitudes and longitudes represent the southern and western hemispheres, respectively.

REFERENCES


In the pre-AIDJEX discussions regarding sea-ice deformation, the desirability of obtaining strain measurements simultaneously at several scales has always been advocated. But now we find ourselves in the awkward position of having a fairly good idea of the kinds of deformation data we need to test our constantly evolving numerical models while at the same time a rapid growth in the technology of strain measurements is taking place. Indeed, at this time I believe it is fair to say that we do not have a firm decision on the kinds of instruments we wish to use to measure strains during the full-scale AIDJEX Expedition in 1973. This situation has made many of the AIDJEX investigators somewhat anxious, since the strain measurements are of fundamental importance to the entire project.

Over the last few years, I have been involved in trying to evolve a method to measure sea-ice strains over a scale of 10-20 km. In the early 1960's I took part in a traverse on the Ross Ice Shelf in which we used tellurometers (Model MRA-2) to great advantage, making shots as long as 40 km to an accuracy of a few centimeters. This instrument proved itself to be capable of withstanding rugged field use and fairly easy to use under trying conditions. It has one great disadvantage compared to some other types of ranging devices: both ends of the line must be occupied, since the remote site does not act as a mere reflector but actually retransmits a received signal. Its single great advantage over other ranging instruments that depend on reflecting a visible light beam, such as geodimeters and lasers, is that it has an all-weather capability and can be used in fog and blowing snow.

Soon after the creation of AIDJEX in November 1969, the Polar Continental Shelf Project of Canada very generously offered to take a dozen U.S. scientists along on its March 1970 expedition to the Beaufort
Sea so that we could test various designs and concepts needed for the planning of AIDJEX. Dr. Fred Roots generously offered me the use of a pair of MRA-2 tellurometers belong to the Polar Continental Shelf Project.

During the first AIDJEX pilot experiment in March 1970, I made a series of tellurometer observations at ranges of from 1 km to 18 km. It was found that at ranges greater than 6 km it was impossible to properly focus the instrument. Since this instrument worked at ranges greater than this on the Ross Ice Shelf, it was concluded that the shortened range on sea ice was due to the fact that the saline ice possessed dielectric properties that caused reflections of the beam.

The shorter-range observations, however, proved most interesting. One day, shooting at a range of 3.56 km over two leads, dilation and contractions of several meters/minute were observed, with two series of alternating dilations and contractions occurring in one hour. These measurements were made using a tower approximately 15 feet high constructed of oil drums at the master station with the remote stations mounted on top of the most convenient high hummock available at the given range. All of these measurements were made completely exposed to the environment, and I concluded that in order to do any kind of reasonably accurate work at such low temperatures for periods greater than an hour or two it would be necessary to mount the tellurometers in tents.

Soon after the termination of this experiment, it became apparent that a repeat performance would take place in March 1971. Although the strain measurements obtained were scanty, they were sufficiently interesting to provide the impetus for generating a plan for a more detailed, larger-staffed strain measuring attempt during the 1971 AIDJEX pilot expedition. Talks with the tellurometer company revealed that their new model (MRA-3) performed over glacier ice at ranges 50-100 percent better than the earlier MRA-2. This instrument uses a shorter carrier wavelength (3 cm) than the MRA-2 (10 cm) and is easier to operate because it does not involve the focusing of a broken ring pattern on an oscilloscope but employs a simple variable nullmeter.

Willy Weeks and I decided to form a joint enterprise to measure strains with tellurometers during the forthcoming experiment and to blend this program in with the ground truth program for the remote-sensing overflights.
which were scheduled to take place during the AIDJEX mission. We early decided that an area measurement was highly desirable and that the simplest area to handle logistically was a triangle. A detailed description of what we accomplished will appear in AIDJEX Bulletin 8 as "The CRREL-USGS Program at Camp 200: A Post-Operations Summary." We succeeded in making a number of closed-triangle strain measurements with high accuracy at ranges as great as 11 km. The strain measurements at this range were in the same ballpark as the ones I had obtained a year earlier. However, in a few cases we observed greater strains, as high as 1.2 percent in 6 hours. Also, we measured extremely rapid dilation rates, as high as 0.5 m/sec. Most of these measurements were made with the tellurometers mounted in tents equipped with small Thermoflex heaters.

We can say with certainty that the tellurometer is capable of measuring strains with ranges as great as 10-20 km over sea ice. However, we can also say with equal certainty that logistical problems involved in manning a triangular array at even these relatively small mesoscale ranges are considerable. Willy and I agree that it would not be possible to do what we did for periods greater than the three weeks we operated unless the program were greatly expanded. There is a good possibility that to expand a tellurometer system to the point at which strains could be measured regularly at frequent intervals would result in prohibitively high logistical costs.

The experience to date indicates that it would be highly advisable to test on the sea ice a ranging device which works with an unmanned remote station, such as laser, geodimeters, and autotape. For the same amount of manpower and for much less logistic support, it might be possible to obtain mesoscale strains in far greater detail and more often by using one of the above than by using tellurometers. A base line approximately a mile in length could be set up on a given floe. By setting up a ranging device at each end, one could triangulate to a whole series of reflectors mounted around the main station at various ranges. The two baseline stations could be built on elevated platforms and enclosed in heated tents or plywood structures. The reflectors could be mounted on towers which would be far higher than the average ridge height on which the tellurometers were used.
Wilson Goddard of the University of California at Davis has assured me that an easily portable telescoping antenna that can be set as high as 100 feet is readily available. Once an array of reflectors is set up around the main camp, it would be necessary to visit them only occasionally by helicopter or ski plane in order to adjust the guys on the mast.

The data collected so far have shown that significant strains occur in sea ice over a mesoscale range on the order of 10 km and that large variations in strains occur at short time intervals. Since we do not know if these strains are similar in sign and magnitude to those occurring simultaneously over larger scales, and since we do not know which scale of deformation must be measured to test predictive numerical ice flow models, mesoscale strain measurements of sea ice must be made during AIDJEX. I strongly suggest that during the 1972 AIDJEX pilot expedition several ranging devices be used in conjunction with the tellurometers to measure sea-ice deformations. The tellurometers can serve as a comparison; and since we are sure they will work, useful strain information will result even if all of the other ranging devices fail. If we are going to have a working program by the time of the main AIDJEX thrust in 1973, it is imperative that we test the most promising and available mesoscale ranging devices next spring.
A REVIEW OF RADIO POSITIONING FOR AIDJEX

by

Pat Martin

The need for all-weather positioning in AIDJEX leads directly to consideration of radio devices. Radio propagation is a variable phenomenon and is related to "radio weather," but many positioning systems are in use which minimize this variability and produce accurate position determinations. Typically in these systems, two or more sources radiate signals whose receptions are carefully measured; a calculation of distances is then made by assuming a propagation velocity. Position errors are a combination of distance errors and the geometry of the radio array. Uncertainties in propagation path and velocity, coupled with errors in measurement of signal arrivals, cause distance errors which are generally proportional to wavelength. Range of reliable radio propagation is also proportional to wavelength.

A review of representative systems which are currently operational provides a basis for meeting AIDJEX positioning needs (Fig. 1). There are three distinct groupings of positioning systems by frequency and wavelength.

Systems which operate at about 100 kc have ranges of several hundred miles provided by 3 km wavelengths and large, high-power antennas. While some such systems provide marginal coverage in areas of interest to AIDJEX, none now exists or is planned to give complete coverage. These systems are very expensive and not very portable.

Systems which operate at about 2 Mc, just above AM broadcast frequency, have wavelengths of about 150 meters and typical ranges of around 200 miles. Most are portable, less expensive, and more accurate when compared to the lower-frequency systems. Unfortunately, well-documented difficulties have been encountered with the use of such systems over sea ice. Apparently penetration of the radio waves into the sea ice causes weak and irregular signals within the radiated pattern, which makes such systems less attractive for accurate positioning over sea ice.
Systems in the microwave or radar bands have wavelengths of less than 1 meter and frequencies above 300 Mc; they are portable, reasonably inexpensive, and very accurate. Reliable ranges are limited to essentially optical line of sight which is determined by the earth's curvature and antenna height (Fig. 2). Antenna heights of 100 feet permit ranges of about 25 miles under normal atmospheric conditions with possible extensions of total range by interlocking grids of shorter-range systems.

This review of network radio positioning systems yields promise only from the short-range systems. AIDJEX will probably need to measure position changes on scales considerably greater than 25 miles, for which purpose few options remain. Nonstandard refraction conditions in the Arctic may permit over-horizon propagation of SHORAN to ranges beyond 100 miles. Further study of radio propagation in the VHF band from 30 to 300 Mc (wave-lengths from 1 to 10 meters) may suggest a unique system to meet AIDJEX needs.

Three worldwide radio positioning systems remain as candidates for beyond-line-of-sight scales. Omega is a radio network system with a frequency of about 10 kc, which results in long ranges and reduced accuracies. The system should give good coverage in the Arctic by early 1973.

Two worldwide satellite positioning systems are notable because they avoid many of the limitations of surface-based radio propagation. NASA's Interrogation, Recording and Location System (IRLS) and the Navy Navigation Satellite System (Transit) both use 400 Mc line-of-sight radio signals from polar orbiting satellites to position receivers on the earth's surface. IRLS is part of a research program and is quite promising for unmanned data buoy applications where limited accuracy is required. [See Haugen, "Experimental Arctic Data Buoy," in this Bulletin.]

Transit is an operational system devoted to highly accurate positioning worldwide. Diverse equipment is becoming available to take advantage of this guaranteed availability of accurate positioning. Transit, like all other positioning systems, has variations in accuracy—in this case, roughly 5 to 500 meters, depending on an amazing number of variables. Knowledge of receiver motions during the signal reception period of about 10 minutes is a very important variable for drifting stations when maximum accuracies are desired.
Fig. 1. Typical Positioning Systems and Their Range.
CONCLUSIONS

The more promising subjects for further investigation are:

1. Line-of-sight systems for ranges up to 25 miles, with grid extensions for longer ranges.
2. Over-the-horizon VHF propagation.
3. Transit for the more accurate long-range positioning.
4. Omega and IRLS for less accurate long-range positioning.
Prior Arctic field experience is essential to the efficient use of any positioning system in AIDJEX. Radio positioning is also closely related to voice and data radio communication and should be coordinated with those efforts in AIDJEX.

BIBLIOGRAPHY


